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ABSTRACT

One dilemma of constructivist modes of instruction, which involve engaging students in discussions concerning a range of possible explanations for a given phenomenon, is that such an approach may confuse students who believe that absolute scientific truth exists. Historical dialogues in which various perspectives are aired by key scientists of the past may have the potential of bridging the conceptual gap. This paper proposes a teaching method using historical dialogues for remediating students' misconceptions. Selection of historical incidents, hints for teaching practice, risks of this method, and long term effects are discussed. A sample history dialogue lesson, "Galileo and Aristotle: A Dialogue," is appended. Three references are listed. (YP)

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HELPING STUDENTS UNDERSTAND DIFFICULT SCIENCE CONCEPTS THROUGH THE USE OF DIALOGUES WITH HISTORY

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During the past fifteen years a substantial body of research has focused on "student alternative conceptions" (see proceedings of Cornell conference, 1987). In essence this work shows that most students harbor views that differ significantly from current scientific thinking and that instruction often has very little effect in changing these views. The most common informed explanation of this phenomenon invokes the constructivist perspective of learning and knowing (Resnick, 1987). The initial existence of these alternative conceptions is explained by the claim that they are constructed by the students, long before they receive formal instruction, as a means of coping with everyday experiences. The persistence of these views is believed to stem in part from their utility and further from the ineffectiveness of expository instruction. Constructivists believe that before students can adopt new concepts they must first be brought to examine those they already hold, find the ways in which they are insufficient, and finally embark on the process of constructing new concepts which may be more adequate to the task.

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Constructivist modes of instruction engage students in discussions concerning a range of possible explanations for some phenomenon. The relative merits of each of the explanations is considered, and no explanation is discarded out of hand. Though there usually is eventual consensus on one mode of explanation, that conclusion is not enshrined as the "truth" but rather is considered a tentative best model. Although this approach is delightfully consistent with current perspectives on the philosophy of science, unfortunately it is at odds with what we know about students. Investigations of student thinking, first conducted by William Perry (1970) and replicated many times since, show that most entering college students have a view of knowledge in which the constructivist approach makes no sense. They believe that absolute scientific truth does exist and that it is the duty of experts to convey that truth to students who, in turn, have the duty to ingest it. The activity of class discussion may therefore be viewed as maliciously confusing or as the teacher's attempt to avoid the responsibility of conveying information. The conflict is perhaps best summarized by stating that in the constructivist perspective part of the teacher's role is to cause perplexity or confusion (and later to help resolve it), while in the traditional view, held by most students, confusion and mental conflict play no useful role at all.

One could respond to the above dilemma by not using constructivist approaches until students are ready for them. Unfortunately there is good evidence (Perry, 1970) that exposure to these approaches is the only device through which students are likely to get ready for them. Thus we are faced with the problem of teaching students in a way that does not make sense to

them, in order to make that way of teaching make sense. It is a situation which is hard to parse.

Historical dialogues in which various perspectives are aired by key scientists of the past have the potential of bridging the conceptual gap. From the students' perspective they are learning the facts of history. Any confusions that may arise are due to the complexity of the historical record and are therefore unavoidable. Yet from the constructivist perspective the dialogues contain all the necessary elements for effective learning. Students are likely to begin studying the history of science believing that they are finding the roots of the truth we now know. But as they begin to understand the merits of older perspectives they may see how our current theories fit into a pattern of evolving beliefs. They begin to see that the concepts of "right" and "wrong" do not apply to scientific theories as well as do the concepts of "useful" and "less useful". Inherent in these latter two terms is the notion of application to some particular purpose.

To obtain all these benefits from the history of science it is essential to have students actively thinking within several different perspectives. The "right" vs "wrong" view of scientific theory is encouraged by cursory treatments that consider only the conclusions of scientific investigations. It is important to go beyond the laws and to discuss the arguments that were made in support of them, as well as the personal struggles of the individuals who fought in each scientific revolution. For example, it is easy to teach students that the sun does not go around the earth; and they will quickly learn to reply that earth goes around the sun. These two facts give a caricature of the scientific revolution, but they distort the process. In

fact they are not logically connected. The first explains the phenomenon of sunset and sunrise. The earth's orbit around the sun explains no commonly perceptible phenomenon. It does not even bear directly on yearly seasonal changes (there are other mechanisms that could be invoked to explain a precessing axis of rotation). It is not until students try working within the medieval model of astronomy that they begin to realize how little data there is within their experience to support a heliocentric view. This helps them to understand Galileo's difficulties and to appreciate the beauty and the uncertainty of modern astronomical theory which is based on long chains of logical deductions from a few difficult observations.

It is of course impossible to take students through every significant debate in the entire history of science. One method for selecting historical incidents is to pick those that concern issues which we know students have difficulty with. There is now a substantial body of research indicating topics in the curriculum where key concepts are not getting through to the students. If the constructivist theory of learning is to prove useful, it is most likely to be with these concepts. Take for example Newton's first law: objects keep moving unless a force is applied to stop them. Aristotle believed that objects tend to stop and only keep moving if acted on by a force. Most modern students fall somewhere in between Newton and Aristotle. They have not carefully considered either position and are unaware of many of the arguments. This is not an issue that can be resolved by a simple demonstration. In fact the best arguments on Newton's side are quite far removed from observation and involve extending ideas to a logical (but unobservable) limit. When you study the issue carefully it is clear why the

switch to the Newtonian view is so difficult. Most everyday phenomena are easily interpreted with the Aristotlean perspective.

Imagine a class of the following form. The night before students have read a dialogue in which Galileo and Aristotle give arguments for their positions. The class is divided into two teams, one representing each side, and they are then given time to prepare for a debate. The debate is held and during it the teacher asks each side to give explanations for certain observations, such as that a ball thrown upward, eventually will fall back down. The situations picked by the teacher represent cases which are known to be particularly troublesome for students to resolve (such as what happens when the ball reaches the top of its trajectory.) It is unlikely that after a single class session there will be a clear resolution to the debate (and it is essential that the teacher does not impose one). Issues which troubled science for several hundred years cannot be disposed of in minutes. Then throughout the remainder of the course occasional assignments will ask students to give a Newtonian and an Aristotlean explanation for some observed event. Ideally such questions should be continued in subsequent courses; it is unwise to treat Aristotle as a mistaken old man, to be proven wrong and then ignored.

There are many risks in the above approach. The "history" which the students would learn might be largely their own construction and bear little relation to the historical record. Indeed the dialogues themselves are distortions of history. The physics generated in class discussion might wander far from that in the text books and students might leave the course with a mixture of beliefs, unclear as to which are correct. Undoubtedly both

of these things will occur. But there is overwhelming evidence that these problems exist in the current curriculum too. The historical dialogue approach is not designed to prevent "misconceptions" but rather to put students in a better position to think through the concepts they hold and to eventually obtain a relatively consistent understanding. It is unclear at this time whether such an approach can have short term benefits as measured by mastery of traditional

content. While one would hope that getting students to think more carefully about the physics they are learning generates a deeper level of understanding this may take more time than the semester provides. The greatest promise is in the long term and resides in the expectation that students will have learned how to construct a consistent scientific perspective, one that continually evolves in response to experience and thought.

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APPENDIX

Sample History Dialogue Lesson

The following lesson is currently being tested. While it has stimulated considerable interest, we have already noted several deficiencies in it. Some of the terminology is confusing to students (e.g. material object, and incline plane). Complex visual situations are described verbally; there is a need for drawings to accompany the text. Notes to the teacher are too vague and do not include any explanation of the pedagogical principles employed. A revised version is expected in 1990 following further field testing.

GALILEO AND ARISTOTLE: A DIALOGUE

(The year is ----. A man with gray receding hair and heavy bushy eyebrows stoops over a table muttering to himself, staring at two incline planes in front of him. He uses a quilled pen in his hand to scratch his hawk-like nose.)

(Groaning he says:) "I must think this through one more time. Now concentrate! Concentrate!!"

(He throws the pen to the table.) "It's just too difficult. My mind is filled with a thousand thoughts and like a child jumps from one thing to another! Why is it that I am unable to focus on a single idea?"

(He runs his hands through his thin hair.) "If only I was not so overcome with anticipation! You see, I think I may have discovered something - something quite remarkable and my excitement is almost uncontrollable. It is hard to imagine that I may change how humanity thinks about motion. My ideas on the matter are so revolutionary I often have difficulty thinking about them."

(He stares about the room that is empty except for the table and chair he sits at. There is no rug on the wood-planked floor or picture to grace the white-washed walls. Only the incline planes, some metal balls, and a block of wood hint at any activity. He sighs.) "Why can't I concentrate!?" *(There was a momentary pause, and then he continued.)* "They probably won't think it's such a great discovery a hundred years from now. Perhaps I'm getting ahead of myself. First things first. I must think it through one more time. No! It's just no use! I just can't concentrate. I know - I'll close my eyes." *(He closes his eyes)* "I'll take five deep breaths," *(He takes five deep breaths)*, and I'll clear my mind." *(He pauses)*. "There! Now I'm ready to think!"

(Slowly he opens his eyes, but then blinks, closes his eyes and then opens them again. He shakes his head, rubs his eyes and looks again.)

"Who are you?"

(Bewildered he looks at the figure standing at the other end of the table dressed in a dirty white dress thing, like nothing he had ever seen before. The man is old, older then himself, with silver hair and a long silver beard. He repeats himself, still not sure how the man had come to be there and not quite believing he was there.)

"Who are you?"

(The older man snapped his fingers and a chair appeared. Gingerly lowering himself to the chair he smiled slightly at the awed expression on the others man's face and answers.)

"Don't you recognize me, Galileo? I am Aristotle."

Galileo: *(Laughing uneasily).* Aristotle huh? Well then my name must be Archimedes.

Aristotle: Hmm, I see. You don't believe me, do you?

Galileo: Would you? After all, Aristotle lived some 2,000 years ago.

Aristotle: Never mind. It doesn't matter whether you believe me. I've come here to talk to you about your er,.. discovery. I heard you have discovered something extraordinary about motion. You probably know I've always had a keen interest in the science of motion. I couldn't resist coming.

Galileo: How did you find out about my discovery!?

Aristotle: Now don't concern yourself so, your discovery is safe with me. As I"ve just told you, I've always had a keen interest in the science of motion. When I heard you had learned something new..., well, you understand.

(He leans forward, places his elbows on the table and licks his pale lips eagerly, as if anticipating a tasty meat pie.)

Aristotle: So tell me what is all the excitement about?

Galileo: Well, mind you, I haven't worked out all the details - but what I think I've discovered is this:

If a material object is at rest it will remain at rest unless acted on by some force...

Aristotle: You call that a discovery!? Why I wrote that down more than 1,800 years ago. And even 2,000 years ago, it wasn't a great discovery...

Galileo: Let me finish!

Aristotle: Sorry.

Galileo: **If a material body is moving it will continue to move with the same speed and in the same direction unless a force (a push or a pull) acts on it.**

Aristotle: Where did you come up with this crazy idea ...?

Galileo: What do you mean crazy ... you, you...!

Aristotle: Now don't take it personally. It's just that your ideas about motion seem to be at odds with what is observed in the world. Not that I have ever been one to pay too much attention to observations. It's reason, not observation that must be emphasized in the search for truth.

Galileo: Go ahead, show me the errors of my ways - if you think you're so smart?!

Aristotle: Alright then. Look around and tell me what you see.

Galileo: A table, two chairs... let me see... the incline planes... I guess I don't understand what you're getting at. None of this has anything to do with motion. Everything that I see is at rest.

Aristotle: Precisely my point. Now don't you think that if objects could move with a constant speed without being acted on by forces that we would see a lot more material objects in motion - at least one object in motion.

Galileo: I must admit that on the surface of things the idea that some object could keep moving in the absence of a force seems dubious. But ...

Aristotle: Here - take this block of wood and give it a push to start it moving.

(Galileo does what Aristotle asks.)

Aristotle: How would you describe what happened?

Galileo: Hmm... Well... The wooden block slowed down... and eventually it came to rest.

Aristotle: Now.. How would you keep the block moving on the table at a constant speed?

Galileo: I guess I would push on the block continuously, with a certain strength.

Aristotle: May I summarize your own observations.

Galileo: Actually, I would prefer...

Aristotle: Generally material objects are at rest, moving objects left to themselves come to rest, and to keep objects moving we must exert forces on them.

It is my opinion that the natural state of objects is one where the object is at rest. I can't imagine what made you think that moving objects will continue to move at a constant speed in the absence of any forces, something has to keep them moving.

Galileo: Ahh... Perhaps you're right. Maybe I was fooling myself into believing I had discovered something truly important.

Aristotle: My, you give up easily. That's no way to make scientific discoveries. You need to work hard. You need to challenge existing notions. You need to try new things. If you fail, and believe me you will fail many times, you must try again. The only reason I'm challenging your ideas is to help you understand them better.

Galileo: O.K. Then let me tell you why my ideas about moving bodies might be right. First, answer me this question: What will happen when I take this metal ball and put it at the top of one of the incline planes?

Aristotle: Well, to be honest with you, I don't have a lot of experience with incline planes. I guess I've always been more of a theorist than an experimentalist.

Galileo: Then watch what happens.

(Galileo put the metal ball at the top of the incline. Both men carefully watch the ball travel down the incline.)

Aristotle: It looks as though the ball started to move, slowly at first, then faster and faster.

Galileo: Now tell me what will happen if the metal ball travels up the incline plane.

Aristotle: Again, I'm not sure, but my guess is that the ball would slow down, perhaps coming to rest for a moment, and then getting faster as it rolls back down the incline.

Galileo: Exactly right, as you can see for yourself.

(Galileo sends the metal ball up the incline. Both men watch intently.)

Galileo: My question to you Aristotle is this: If the ball speeds up when going down the incline and slows down when moving up the incline what will the ball do if the ball is on a level surface?

Aristotle: I suppose you want me to say that it neither speeds up or slows down; in other words, the speed stays the same forever. I must admit that the argument you're trying to construct is a tempting one but it must be flawed. We both know that the ball will actually come to rest.

Galileo: But can we argue that the metal ball will slow down on a level surface? If we imagine the level surface is tilted by an imperceptible amount, we would go from the case where the ball slows down to a case were the ball speeds up. This seems impossible to me.

Aristotle: But you need to explain why the metal ball, or the block for that matter, eventually comes to rest on a level surface.

Galileo: Well, take the block and give it a gentle push on the table.

(Galileo watches Aristotle push the block on the table.)

Galileo: O.K., now push the block with the same strength, only this time do it on the floor. *(Aristotle does so.)* O.K., now gently toss the block into the air... Do you see what happened?

Aristotle: The block moved differently in each case. In particular, the block ended up a different distance away.

Galileo: Why did they go a different distance in each case? What this suggests to me is that how quickly an object comes to rest depends on what surface or medium it's in contact with. It seems that the smoother surfaces bring an object to rest more slowly than do rough surfaces. Hence, an object travels further on smoother surfaces than rough surfaces if the object starts out in the same way on both. I can imagine a surface so smooth that an object in motion would never come to rest.

Aristotle: You do have quite an imagination, but we are trying to discover truth, not dabble in idle speculation. Do you have any further arguments or demonstrations to support your conjectures?

Galileo: I have a very nice demonstration as I'm sure you'll agree.

Aristotle: We shall see.

Galileo: Let me take this metal ball and let it roll down the first incline and roll up the second. Tell me what you see.

(Both men watch as Galileo lets go of the ball.)

Aristotle: Why, this is quite interesting. The metal ball rose to about the same height on the second incline as the height it was released from on the first. But I'm not sure I see what this has to do with objects moving with constant speed in the absence of forces.

Galileo: Let me replace the second incline with one that's not so steep. I'll release the ball on the first incline from the same place as last time. Tell me what you observe in this case.

Aristotle: Quite remarkable! The ball came to rest on the second incline at about the same height as it did last time. This seems strange given that the ball traveled a greater distance.

(Aristotle motions to Galileo showing him the difference in distance the ball traveled.)

Galileo: Here is the critical step. Imagine choosing the second incline so that each new time we do the experiment we use a smaller slope.

But each new time, the metal ball always rises to the same height before stopping. (I have done this and can verify that it is approximately true.) What do you think will happen if we remove the second incline altogether?

Aristotle: It would seem that as with the previous cases, the metal ball will continue to move until it reaches a height equal to the height from which the ball was released. But given that the ball can never reach such a height on a level surface the metal ball will move forever.

Galileo: Yes! That's exactly how I would have reasoned it. Well what do you think?

Aristotle: It's hard to say. You see I'm an old man and rather stuck in my ways. When I begin to examine what you have to say, I see contradictions everywhere. But perhaps this reflects difficulties with other things I hold to be true. Let's face it, you wouldn't be the first to improve on my ideas, or the last. The only thing I can say to you is to tell others of your ideas. Time alone will be the judge. One word of warning. Don't be too disappointed when your ideas are replaced by better ones a year, 50 years, or a 1,000 years from now, because they most certainly will. As great as your discovery may be, you and it will eventually be lost in the pages of time.

Galileo: You sound so pessimistic. But never mind, I must write about my work so the whole world will see what I have discovered.

(Galileo grabs his pen and sits down to write. He speaks to Aristotle while his eyes remain fixed on a piece of paper. The figure of Aristotle disappears.)

Galileo: What point do you think I should make first. It so important to make a good first impression - I'm sure you know. Perhaps if you can stay around for a while we could work together. You ask some great questions. They certainly help a person to clarify their thoughts... Aristotle? ...Aristotle!?

(Galileo lifts his head. He slowly looks around the room. Muttering to himself, he scratches his hawk-like nose with his quilled pen.)

* * * * * *